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EDITOR
C. A. CHANT
University of Toronto, Toronto

ASSOCIATE EDITORS
J. S. PLASKETT
Director of the Dominion Astrophysical Observatory, Victoria, B.C.
SIR FREDERIC STUPART
Director of the Meteorological Service of Canada, Toronto

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THE JOURNAL
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ROYAL ASTRONOMICAL SOCIETY
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VOL. XVIII APRIL No. 4

THE APPLICATIONS OF MODERN PHYSICS TO ASTRONOMY

A CONDENSED REPORT OF A COURSE OF LECTURES DELIVERED AT THE UNIVERSITY OF TORONTO, FEBRUARY 12 TO 29, 1924, BY HENRY NORRIS RUSSELL

By H. F. BALMER

I. THE SIZE AND EXTENT OF THE UNIVERSE

A Model of the Universe

IN the study of the stellar universe the first thing necessary is an accurate knowledge of its size and extent. In other words, before considering *what* the stars are, we must know *where* they are. In order to get an adequate idea of the distribution and distances of the stars let us construct for ourselves a model, such that one inch shall represent one hundred million miles. On this scale the sun will be represented by a grain of sand and the earth may be represented by an average-sized microbe less than one inch distant from the sun. The other planets of our solar system will also be microscopic in size, the nearest being about one quarter of an inch from the sun and the farthest not much more than two feet away!

The stars, too, will in general be represented by sand grains, although some may be of the size of pebbles and a few even of the size of golf or tennis balls, and will be spread out so that the distance from each star to its neighbour will be four or five miles. These stars will be distributed approximately in a plane one hundred and fifty or two hundred thousand miles in diameter, although this distance will not be adequate for some stars, which will require one million miles on the scale of our model. Stars are not confined to this plane—the Milky Way—however, and are to be found from three to five thousand miles on either side of it.

Trigonometric Determination of Parallax

These distances are somewhat startling, and in order to justify them the method by which they are measured must be explained. In the determination of the distances of the nearer stars the underlying principle is that of the range-finder as used in the army and the navy. This instrument consists essentially of a tube at each end of which is a mirror which can be turned, the tube being placed at right angles to the direction of the object whose distance is to be determined. If this object is at an infinite distance the rays of light from it to each mirror will be parallel, but if it is fairly near, the rays from it to each mirror will not be parallel, and hence the mirrors must be turned a little in order to produce the image at the same place as in the case of the object at an infinite distance. Now the angle through which the mirrors must be turned is equal to the angle subtended by the tube at the object, and thus if we know the length of the tube we can readily determine the distance of the object.*

Since a range-finder having a base of one yard will measure distances fairly well only up to two or three miles, it is quite evident that a much longer base will be necessary to measure even the smallest stellar distance. Fortunately we are provided with such a base line, due to the revolution of the earth around the sun. At one time we are on one side of the sun and six months later we are on the opposite side, and thus are a distance of two astronomical

*In the instruments actually constructed the mirrors at the ends of the tube are not turned. It is found more convenient to measure the change in direction of the rays of light in another way.—H. F. B.

units away from our former position. We now require a method of measuring the angle corresponding to the angle through which the mirrors were turned.

Let us consider for a moment that we are looking out of a window from the opposite side of the room at a distant landscape. We notice that one of the sides of the window is coincident with some object in the landscape. We now shift our position slightly to the left and notice that the side of the window is no longer coincident with the object in the landscape but has apparently shifted to the right. A slight consideration will show that the angle at our eye between the edge of the window and the new position of the object in the background is equal to the angle subtended at the edge of the window by the distance through which we moved, thus enabling us to determine the distance to the window.

The case of stellar distances is similar to this. Our landscape or background is now composed of the very faint stars which are very far away; our window edge corresponds to the bright and relatively near star whose distance we wish to measure; and the distance through which we move, our base line, is twice the distance of the earth from the sun. Hence, theoretically, the problem of measuring the parallax of a star, which is simply the angle subtended at the star by half the diameter of the earth's orbit, is quite simple. All that must be done is to take two photographs, one when the earth is on one side of the sun and one when it is directly opposite on the other side, and measure on the photograph the angular distance of the star from the stars forming the background in each case, the difference giving twice the parallax. In practice, however, the problem is by no means as simple as this.

Each star is moving across the sky with a motion of its own, as well as having an apparent motion due to the movement of the earth in its orbit. Were the earth to remain stationary, the apparent path of the star would be a straight line; but, due to the motion of the earth, the apparent path is not a straight line but one having a wave form (Fig. 1). Consequently the parallax, instead of being the measured shift of the star in six months, is measured by the displacement of the star from one side to the other of the straight line which would have been its apparent path

were there no parallactic shift. In order that good results be obtained certain precautions are necessary. Since stars are not stationary but shift about a little, due to refraction in the earth's atmosphere, a bright star will give a fairly circular image having slight irregularities, produced by shifts from its normal position. Even if these show only when examined with the microscope the

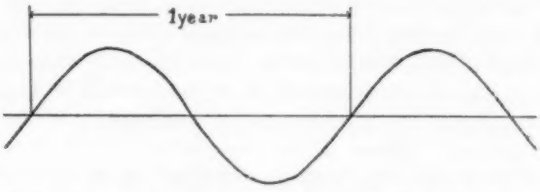


Fig. 1. The revolution of the earth about the sun causes the star to appear to move back and forth across the line of its proper motion.

plate must be discarded. Consequently the light must be cut down until the star images are of the same relative brightness and fairly faint. This effect is produced by giving a number of almost instantaneous exposures on the bright star and a continuous exposure on the fainter ones.

Moreover light from differently coloured stars is refracted by different amounts, and consequently the photographs of any star must always be taken with the telescope pointing to the same point in the sky (that is, at the same elevation) in order that the refraction may be the same in all cases.

If these precautions are taken, a dozen plates will yield a result the probable error of which is five per cent., that is, the chance that the result is within five per cent. of the actual value is equal to the chance that it is beyond five per cent. of the actual value. When we consider that different observers at different places obtain results in close agreement, we must conclude that the measurement is of the star and not of the atmosphere, and that we have a fairly accurate method of measuring the parallaxes of the nearer stars. Having determined the parallax π in seconds of arc it is a simple matter to determine Δ, the distance of the star in astronomical units* for $\Delta = 206265/\pi$.

*An astronomical unit is the mean distance of the earth from the sun, or 93,000,000 miles.—H. F. B.

When this is reduced to miles, our largest ordinary unit of length, the number becomes much too cumbersome to handle, and consequently new units have been invented. The one most commonly used is the "light-year," which is equal to the distance light travels in one year. Since light travels at approximately 186,000 miles per second it is a matter of simple multiplication to find that one light-year is equal to six thousand billion miles or sixty-three thousand times the distance from earth to sun. To find the distance of a star in light-years the following equation is used, $D = 3.26/\pi$. The other unit, most commonly used by astronomers is the "parsec." This is the distance at which a star would have a parallax of one second of arc.

Since there are probably about three or four hundred telescopic stars within a distance of thirty-two light-years, it has been computed that the stars are on the average four or five light-years apart, one light-year being represented on our model by one mile.

The Drift Method

By the trigonometric method distances up to about ten million times the earth's distance from the sun can be measured with an accuracy of from 15 to 20 per cent. But certainly distances over one hundred light-years cannot be measured by this method, and this "beggarly" distance is by no means sufficient to account for everything in the stellar universe. Consequently beyond this distance a different method is necessary. This method is based on the motions of the stars themselves and does not give individual results, but average results for groups of stars. Observation shows that all stars are in motion across the heavens, some in one direction, others in another. The largest motion is about 10″ per year. At this rate it would require over 350 years to move one degree. This seems quite slow according to ordinary standards, but it is in reality quite rapid, for photographs taken only a week apart show it quite readily. Hence a comparison of photographs taken years apart enables us to measure very small motions. These motions of the stars are in all directions and at different rates—seemingly following no definite law. But a moment's thought will show that there is order in this apparent disorder.

Let us for a moment imagine that we are on a ship proceeding at a definite speed in a definite direction at night and that, all

around us on the ocean, are other ships moving in other directions at other speeds. What we shall see will be a number of lights moving about on the surface of the ocean. Let us now look over the bow. We shall notice that the same number of ships pass from port to starboard as pass in the opposite direction. If we look directly astern we shall notice the same thing, for on the average the number going in one direction is equal to the number going in the other. Let us now look to either side. The ships which pass from the stern to the bow will be those which are going in the same direction as we are and at a faster speed, while all others will pass from bow to stern. Moreover, if we are moving slowly the number of ships passing from stern to bow will be comparable to the number passing from bow to stern, while if we are moving fast the number passing from stern to bow will be much less than those passing in the opposite direction. Thus by counting the number passing in each direction we can readily determine our own direction of motion.

In the heavens the problem is exactly the same, only in three dimensions. Hence the direction of the sun's motion can be found. In order to find the rate at which the sun is moving we have recourse to spectroscopic observations. Since light is transmitted by a wave motion in the ether, if we are approaching a star we shall receive more waves per second than if we are at rest with respect to the star. This will cause a line to shift from its normal position a little toward the blue end of the spectrum. If, however, we are moving away from a star we shall receive fewer waves per second than we would if we were at rest, causing a shift toward the red end of the spectrum. Now this shift can be measured and hence our speed toward or away from a star can be determined. At present our speed with respect to about a thousand stars has been determined and in a few years we shall know our speed with respect to all stars visible to the naked eye. Now in the direction toward which the sun is moving, which is known as the "apex of the sun's way," the large majority of the stars will appear to be moving towards us and in the direction of the antapex (that is, the point 180° from the apex) the majority will appear to be moving away from us, while in directions at right angles to the direction of our motion, on the average the number moving toward

us will be the same as the number moving away from us and hence their average velocity toward the solar system will be zero. At the apex the average velocity will be toward our system and at the antapex the average velocity will be away from our system. Thus by spectroscopic methods we are able to determine both the direction and velocity of the sun's motion.

By proper motion measurements, that is, motions across the sky, Boss determined the position of the apex to be R.A. 18^h, Decl.$+35°$, while by spectroscopic methods Campbell found it to be R.A. 18^h, Decl.$+25°$, and the velocity of the sun to be 20 km. per second.* These two results are not in very close agreement, the fault probably being in the proper motion measurements. These measurements rely on observations made a hundred years ago and which are perhaps less accurate than more recent ones. Possibly, too, there has been some systematic error throughout, which has resulted in placing the position of the apex too far north. Indeed it is probable that a careful study will reveal this error and remove the discordance of the two results.

Now let us consider groups of stars at right angles to the direction of the sun's motion. The average motion backwards is due solely to the sun's motion, since the proper motions average out. Now, at the rate of 20 km. per second the sun moves through four astronomical units per year. Hence, as seen from one of a group of stars, the sun moves through four times the average parallax of the group. Consequently the average drift backwards per year of a group of stars is equal to four times the average parallax. Taken over a number of years this method gives a much greater base line and is applicable to greater distances. By this method the average distance of stars visible to the naked eye is found to be between 300 and 400 light-years. We are now enabled to determine the parallax of the reference stars used in the first method. When this is done we find that the average telescop c star of the ninth or tenth magnitude has a parallax of $0''.003$, which corresponds to a distance of slightly over 1000 light-years.

*These are rough approximations. Boss's result from 5413 stars is R.A. 270°.5, Decl. +34°.3, velocity 24 km. per sec.; Campbell's result is R. A. 272°, Decl. + 27° 26′, velocity 17.8 km. per sec. (See *Astro. Jour.*, vol. 26, p. 112, 1910; Campbell, *Stellar Motions*, p 189.) —H. F. B.

These results enable us to say that the faster moving group which we were able to measure by the "range-finder" method is composed of about one-sixth of the stars visible to the naked eye and that these stars are at an average distance of 80 light-years.

Photometric Method

There is still another way of measuring stellar distances—the photometric method. This is much more powerful for extremely great distances and consists, generally speaking, of a comparison of the brightness of two stars. The brightness of each star is diminished by a known amount until they appear equally bright. To do this the stars are placed out of focus and photographed. If in one minute's exposure one star at a certain distance from the focus gives the same shade as the other star at another known distance from the focus the relative brightness can be readily obtained. In order to have a convenient way of stating relative brightness Hipparchus invented the system of stellar magnitudes, a star of the first magnitude being an average bright star and one of the sixth magnitude being just visible to the naked eye. It has been found that there is a hundred-fold change in brightness in the five magnitudes, a first magnitude star being $2\frac{1}{2}$ times as bright as a second magnitude star, one of the second magnitude being $2\frac{1}{2}$ times as bright as one of the third, and so on. Hence the scale of magnitudes is a logarithmic scale, since as the brightness varies in a geometric progression the magnitude varies in an arithmetic progression. This scale shows how bright stars *appear* to us, not how bright they actually are. In order to determine the magnitude (m) of a given star the following equation may be used:

$$m = 2.5\ [\log l_o - \log l],$$

where l_o is the measure of the light from a standard star and l is the measure of the light from the star whose magnitude is required.

In order to find the actual brightness, the magnitude must be considered in conjunction with the parallax. The actual brightness of a star is described by its *absolute magnitude*, which is the apparent magnitude it would have if placed at a standard distance from us. The standard distance used by Kapteyn is a distance of

10 parsecs, which gives the following relation between apparent and absolute magnitudes:

$$\text{Absolute Magnitude} = M = m + 5 + 5 \log \pi.$$

On this scale tremendous differences are noticed. On the visual magnitude scale the apparent magnitude of the brightest star, Sirius, is -1.6, while that of the sun is -26.7, the sun being apparently many billion times as bright as Sirius. But on the absolute scale the sun is only one-twentieth as bright as Sirius. In general, on the absolute scale stars vary from 100 times brighter than the sun to 1000 times fainter, although there are some exceptions to this rule, Antares being 3000 and Rigel about 10,000 times brighter.

Distances from Variable Stars

Now if from some physical peculiarity of a class of stars we can find their actual brightness, and we know their visual brightness, all that we need do is to substitute these values in the equation

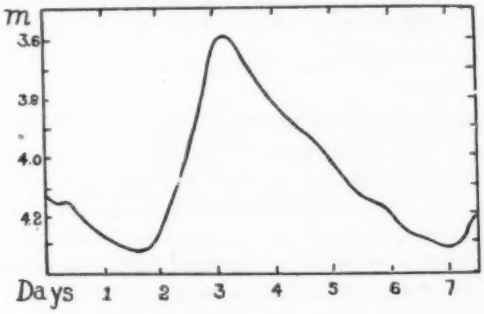


Fig. 2. Light curve of Delta Cephei

connecting absolute and visual magnitudes, and we are able to determine π. For this purpose the best stars are the Cepheid variables, so called from δ Cephei which has a period of about five days and which varies in brightness about 0.7 magnitude. The light curve of this class of variable somewhat resembles a sine curve (Figs. 2, 3). Many of the Cepheids are visible to the naked eye, and their distance is determined with certainty by the "drift"

method to be between 100 and 200 parsecs. Hence these stars are extremely bright, their actual brightness being about 800 times that of the sun. Now there are in the southern sky patches resembling the Milky Way, but which are not in it. They are known as the Magellanic Clouds and they are shown by photography to consist of about a million stars. A comparison of photographs of these clouds shows that the stars vary greatly in brightness and that their light curves and periods are characteristic of the Cepheid variables. In these Magellanic Clouds the bright stars

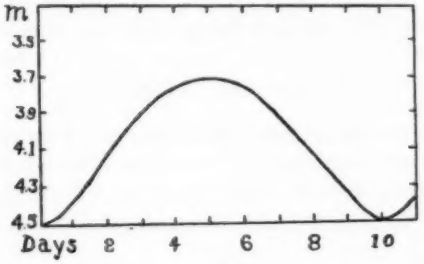


Fig. 3. Light curve of Zeta Geminorum

have periods of about one hundred days, while the periods of the faintest stars are hardly more than a day. Moreover, a perfectly definite relation is shown to hold between the brightness and period (Fig. 4). Also, since these stars are in the one cloud they are at the same distance from us and consequently the apparent brightness is also a measure of the real brightness. Now we know the actual brightness of Cepheids with a period of five days, and consequently we can determine the actual brightness of stars of this type having periods of from one day to one hundred days.

If now in any group of stars we can find stars of the Cepheid type, we can determine their actual brightness from their period and, combining this with their apparent magnitude, we can find their distance. This method has enabled us to determine the distance of the brighter star clusters to be 20,000 light-years and that of the fainter clusters to be ten times this distance. When we consider the case of the faint cluster in Sagittarius, in which the

brightest stars are of the 19th magnitude, we slightly alter our method. In other clusters we find, say, 5000 stars of the same absolute magnitude as our sun, and of a certain visual magnitude. If now we assume that these clusters are practically identical, a comparison of their visual magnitudes will enable us to determine

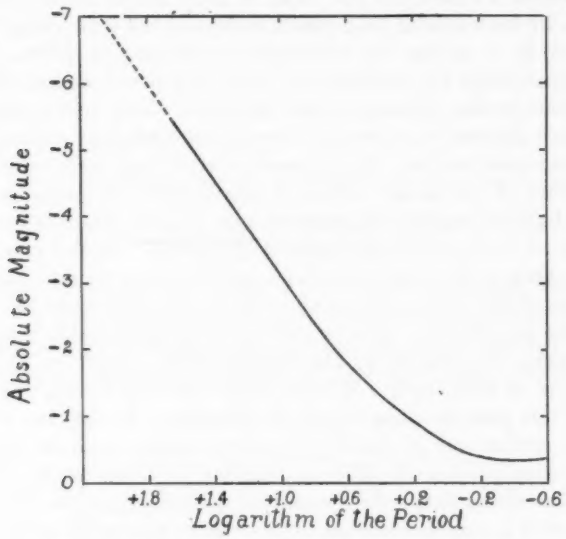


Fig. 4. Diagram showing the relation between brightness and period of the Cepheid variables

their relative distances. In the case of the cluster in Sagittarius the distance is of the order of one million light-years, or one million miles on the scale of our model!

Thus our three methods of measuring stellar distances are:

1. "Range-finder" method, having an extreme limit of about 150 light-years.
2. "Drift" method, having an extreme limit of about 1500 light-years.
3. Real and apparent brightness method, recognizing physical characteristics, having an extreme limit of two or three million light-years.

II. The Sizes of the Stars.

Diffraction of Light Waves

In describing our model we have said that the stars will, in general, be represented by sand grains although some will be represented by pebbles, golf balls or even tennis balls. In other words, we have stated that the diameters of the stars range from a fraction of a million to hundreds of millions of miles. These statements must be justified, and to do this it is necessary to state how these stellar diameters are obtained. Now unless the stars are much greater than the sun it would be useless to expect to see them as round bodies. For suppose that the sun were removed to a distance of one parsec, which is nearer than the nearest star; it would have an angular diameter of only 0″.009, which is the same as that of an inch at a distance of 320 miles. In this case, then, the problem is the same as seeing a golf ball as a round object at a distance of 320 miles. Even with our largest telescopes this would be quite impossible. This is not, as may be thought, caused by insufficient magnification, the reason being found in the very character of light itself. Waves of light passing through an opening, in this case the objective of the telescope, do not pass straight on but spread out in exactly the same manner as will waves on water after passing through an opening in a sea wall. This is known as diffraction. As a result of this phenomenon, the image of a star is a disc surrounded by a series of concentric rings. For an aperture of one inch the diameter of the disc is 4″.6 of arc and for an aperture of ten inches is 0″.46, the diameter of the disc varying inversely as the diameter of the opening. Consequently in order to reduce the diameter of the spurious disc to the angular diameter the sun would have, at a distance of one parsec, an objective 42 feet in diameter would be necessary, a thing at present impossible and very improbable in the future. As a result we must rely on indirect methods of measurement, of which there are three.

Eclipsing Variable Stars

The first and oldest method is applicable to eclipsing variable stars. These stars remain at a constant magnitude for some time, following which their brightness decreases rapidly to a minimum.

After remaining constant at this minimum for a brief interval the brightness increases to normal as rapidly as it fell. After remaining stationary for some time it falls again, but not to the same extent as before, remains at a minimum for a short time and

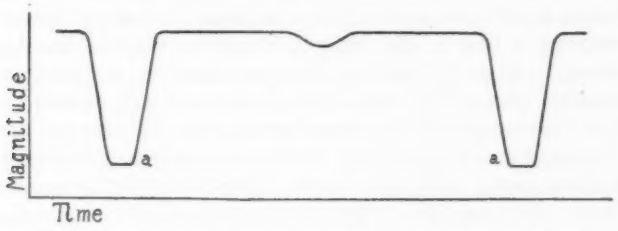


Fig. 5. Light curve of an eclipsing variable, showing steady brightness for some time at the chief minimum, *a*, *a*.

then rises to normal, after which the whole cycle is repeated (Figs. 5, 6). Let us consider for a moment how this change in brightness is produced. It is evident that this variable star is in reality two stars, each revolving around the other, one being larger and brighter

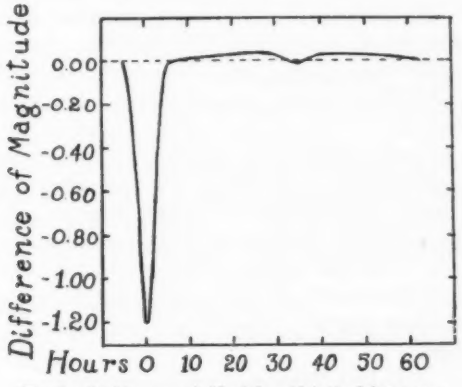


Fig. 6. Light curve of Algol, in which the fainter star does not get completely in front of the brighter star

than the other. Moreover, we must be situated in the plane of their orbits so that, as we look at the stars, they would seem to move to right and left along a straight line. When the fainter

star begins to pass in front of the brighter, the light from the system will begin to decrease, and it will continue to do so until the fainter star is completely in front of the brighter one. Now since the brighter one is larger, the smaller one will remain in front of it for a short time, during which the light from the stars will remain constant at the minimum value. Then, as the smaller passes from in front of the larger the brightness will increase again, reaching its maximum value at the time when the smaller star has just passed from being in front of the larger. The smaller loss of light is caused similarly by the eclipsing of the smaller fainter star by the larger and brighter one. It has been found that an observation of the period and light curve of this type of star enables us to draw a diagram, giving the relative sizes of the two stars and of their orbit, the only thing necessary to complete our information being a scale of miles. This scale is supplied from spectroscopic observations in which measurement of the shift of spectral lines enables us to determine the velocity per second of the star. For, if we know the velocity per second and the time of revolution of the star in its orbit, we know immediately the diameter of the orbit in miles and hence, from our diagram, the diameters of the stars themselves. Measurements made by this method show that these stars are either equal to or larger than our sun, although they are not enormously larger, being two, three, five, and perhaps eight, times as large. That is, they are all within a few million miles of each other in size.

But the question arises as to whether these eclipsing variables are typical of all stars. Probably not, for these variables are white stars, while many others are yellow, orange, red, or blue, in colour. Moreover, the distances of these variables are measurable by the "drift" method; and we thus find that they are *much brighter* than the sun while, in general, the brightness of the other stars is sometimes greater, sometimes equal, sometimes less than that of the sun.

Colour Dependent on Temperature

From a consideration of the common incandescent lamp we see that the hotter the source, the whiter the light given off and also the greater the quantity of light given off. If we pass a small amount of current through the lamp the filament glows with a

feeble red light. On increasing the current the filament glows more brightly, its colour changing from red to orange. A further increase of current greatly increases the light and causes the filament to appear white, while if the current is increased beyond the normal capacity of the lamp the amount of light is still further increased, the filament appearing to be somewhat bluish in colour. Let us now examine the stars. Some, like Sirius, Vega, and the stars in the belt of Orion, are conspicuously blue-white; others are white; others, like Arcturus, orange; and still others, for example, Betelgeux, are red. Hence we conclude that the red stars are comparatively cool stars and that the white stars are quite hot. Moreover, a tungsten lamp, which ordinarily appears white, if examined at a distance, appears reddish in comparison with the stars. Consequently we can say that even the red stars are hotter than ordinary sources of light.

Planck's Law of Radiation

Now if we assume that the stars are perfect radiators, Planck's law gives us the relation between the amount of light given off at a definite wave-length and the absolute temperature of the body. This law is given by the formula

$$J = c_1 \lambda^{-5} (10^{k/\lambda T} - 1)^{-1},$$

where J is the amount of light given off per unit area, λ is the wave-length of the light given off, T is the absolute temperature of the body, and c_1 and k are constants which can be determined experimentally, k being 6220 with the usual units.

Let us now suppose that the star is a perfect radiator in space at a temperature T, that λ is the wave-length of emitted light, and that the diameter of the star is R times the diameter of the sun. If we consider the area of the sun to be the unit of area, then

$$L = JR^2,$$

where L is the light given off by the star.

Now we also have for the absolute magnitude of a star the following relation:

$$M = 2.5 \, [\log L_o - \log L]$$

where L_o is the amount of light from the standard star and L is the amount of light from the star observed.

If now we substitute the first two of these equations, in the third we have

$M = C - 5 \log R + 15550/\lambda T + x$, where $x = 2.5 \log (1 - 10^{-k/\lambda T})$.

This value of x may be neglected as it introduces an error of no more than 15% even for the hottest star, so that our equation may be written:

$$M = C - 5 \log R + 15550/\lambda T.$$

We now utilize a known case in order to determine the value of C.

In the case of the sun the absolute visual magnitude is 4.8 and the temperature is 5800° C.

We also know that the light which most strongly affects the eye has a wave-length of 0.516 microns. By substituting these

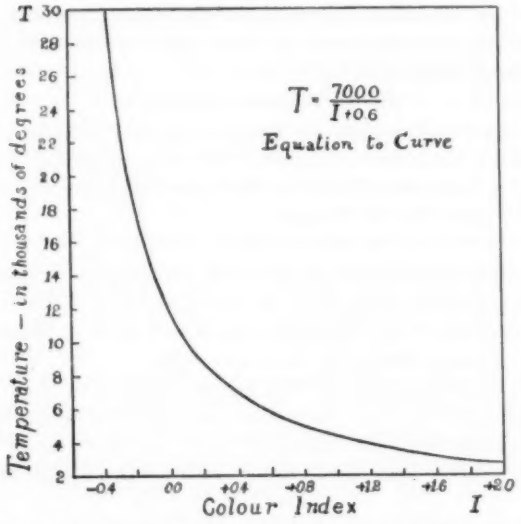


Fig. 7. Curve showing the relation between colour index and temperature

values in the equation C_v (*i.e.*, the value of C for visual rays) is found to be -0.4. Thus we may write

$$M_v = -0.4 - 5 \log R + 30000/T,$$

where M_v is the absolute visual magnitude.

Also the sun's absolute photographic magnitude is 5.4, and the light most strongly affecting the photographic plate has a wave-

length of 0.419 microns. From these values C_p is found to be -1.0. Thus we may also write

$$M_p = -1.0 - 5 \log R + 37000/T$$

where the subscript p indicates photographic values.

By subtracting these two equations we obtain the "colour index," which is the difference between the magnitude of a star determined photographically and visually.

$I = M_p - M_v = -0.6 + 7000/T$, and hence $T = 7000/(I + 0.6)$.

This relation is exhibited graphically in Fig. 7.

From this it is seen that the colour index is independent of the size or distance of the star and depends, assuming ideal radiation, only on the temperature. Consequently a determination of the colour index enables us to determine the temperature of a star. The following table shows results obtained in this manner.

TEMPERATURES OF THE STARS

Star	Type	Colour Index	Temperature
Orion Belt.....	B	−0.3	23000
Vega..,.....	A	0.0	11500
Sun.....	G	+0.6	5800
Arcturus.....	K	+1.1	4100
Antares.....	M	+1.75	2900

This shows that the temperature of the coolest star is approximately the same as that of a tungsten filament at its highest temperature, and that stars like Arcturus are at the temperature of the electric arc. Thus we may say, generally speaking, that the temperatures of the stars begin where those obtainable in the laboratory end.

Diameter, Colour Index and Absolute Magnitude

If now we put the value of T in terms of I in the equation for absolute magnitude we shall have a relation involving only R and M_v. This relation may be written

$$\log R = 0.44 + 0.86\, I - 0.20\, M_v.$$

Now we also have $M = m + 5 + 5 \log \pi$

where m = apparent magnitude, π = parallax and $d'' = \frac{1}{107} R\pi$ where d'' = diameter in seconds of arc.

On substituting these in the equation giving the value of log R, we obtain

$$\log d'' = -2.6 + 0.86\, I - 0.20\, m.$$

Hence the diameter of a star in seconds of arc can be obtained if we know the apparent magnitude and the colour index. The following table shows some of the results obtained by this method.

Star	m	M	π	I	R	d
			"			"
Sirius	−1.6	1.3	0.37	+0.1	1.8	0.006
Vega	0.1	0.3	0.11	0.0	2.4	0.003
Arcturus	0.2	0.0	0.020	+1.1	25	0.025
Betelgeux	0.9	−2.8	0.018	+1.6	250	0.040
Antares	1.2	−4.0	0.009	+1.75	550	0.045
Orionis	1.7	−4.5	0.006	−0.3	12	0.0006
Aldebaran	1.1	0.4	0.060	1.5	5.5	0.031

Diameters by the Interferometer

The third and most recent method of measuring stellar diameters is due to Prof. Michelson, who made use of the very property of light which caused the spurious discs of stars, to overcome the

a *b* *c*

Fig. 8. *a*. Image of a planet when viewed in a telescope. It has a sharply defined disc, which appears larger when the magnification is increased. *b*. Image of a star showing a diffraction ring but having no sharp outline. *c*. Image of a star when a plate with two slits in it is placed over the objective. Note the interference fringes across it.

difficulty which it presented. Suppose across the mirror of our telescope we place an opaque screen containing two long, narrow, parallel slits. If now we examine a point source at an infinite

distance we find that its image is a spurious disc as before, but crossed by alternate light and dark lines in the same direction as the slits (Fig. 8.) And if we move the two slits closer together we shall see that the fringes become wider apart and that the farther the slits are apart the closer are the fringes. Let us consider now what will be the effect produced by two equally bright stars close together. Each star will produce its own pattern, and if the line joining the stars is at right angles to the direction of the slits, these fringe patterns will lie one on top of the other. If now we could shift our stars farther apart or closer together we could arrange them so that the dark fringes from one star would fall exactly on the bright fringes of the other, resulting in a continuous patch of light. Now, although the stars cannot be shifted, we have yet another way of shifting the fringes, that is, by changing the position of the slits. If we change the distance apart of the slits we can obtain the same effect of a continuous disc of light when dark and bright fringes coincide. If now we measure the distance apart of the slits when the fringes disappear we can calculate the angular distance apart of the stars. This method was first used to measure the separation of the components of Capella, giving the value with a precision before unattainable.

Let us now apply this method to measure the diameter of stars. We may consider the disc of a star to be composed of two semicircular discs in contact, each disc being equivalent to a star shining separately. The effective centre of each star will be somewhat nearer the centre of the disc than the edge since there is a greater area along the line joining the two semicircles. The distance apart of these centres has been calculated to be approximately 40 per cent. of the diameter of the star. As we move the slits farther and farther apart the bright fringes from one half become more nearly coincident with the dark fringes from the other and finally disappear. From the distance apart of the slits when the fringes disappear we calculate the value of 40 per cent. of the diameter and hence of the whole diameter.

When this method was tried at Mount Wilson it was found that for the full aperture of one hundred inches the fringes became fainter but did not disappear. This made it necessary to devise some means whereby the slits might be separated still farther.

In order to accomplish this, a beam was arranged across the end of the telescope perpendicular to its axis (Fig. 9). This beam carried four mirrors inclined at 45 degrees to the beam. The central two were stationary and so placed that light parallel to the beam, and from the end nearest each mirror, would be reflected down the telescope parallel to its axis. The other two, which could be

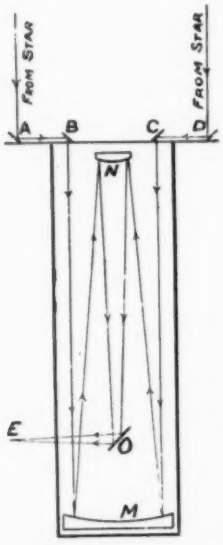


Fig. 9. Diagram illustrating the optical arrangement used in the measurement of a star's diameter. Four plane mirrors, *A*, *B*, *C*, *D*, were mounted on a steel beam bolted across the tube of the telescope. The light from the star followed the paths indicated and ultimately reached the eye at *E*

moved along the beam, reflected light from the star along the beam to the inner mirror. Thus the two outer mirrors, which could be separated a distance of twenty feet, take the place of the slits previously used.* On pointing the instrument to Betelgeux it was found that the fringes disappeared with a separation of ten feet, while when pointed to other stars with this separation the

*The apparatus is described in the *Astrophysical Journal*, vol. 53, page 249.—H. F. B.

fringes remained. This showed that the disappearance was not caused in the instrument or by our atmosphere and that it was due to the star itself. Antares, Arcturus and Aldebaran were also measured by this method. The following is a comparison of the diameters as calculated and as observed by Michelson's method.

Star	Diameter	
	Calculated	Observed
Betelgeux	0."040	0."045
Antares	0. 045	0. 040
Arcturus	0. 025	0. 019
Aldebaran	0. 031	0. 021

These two sets of results are in fairly close agreement and consequently the assumption that the stars radiate as black bodies is almost justified. There is at present in course of construction at Mount Wilson an apparatus permitting of a separation of fifty feet. This will make possible the determination of the diameters of many more stars. If these observed values agree sufficiently with the calculated ones we shall be able to say that the theory of black body radiation holds for all stars, and consequently we will be able to calculate R for all stars.

III. The Masses of the Stars.

We know that, although comparatively rare, there are stars which are extremely large compared with the sun. Antares, for example, has a diameter over 500 times that of the sun, and consequently its volume is over 100,000,000 times that of the sun. The first thing that we ask ourselves is whether the quantity of matter in a star corresponds to its bulk. This brings us to the determination of the masses of the stars.

The Force of Gravitation

Now the only way in which we can measure the quantity of matter in a body is to measure the gravitational attraction which it exerts on other bodies. This gravitational force is very weak and requires the presence of huge masses in order to exert a measurable amount of force. To illustrate this let us take a balance and

on each pan place a 10-pound ball of lead, adjusting the balance so as to be in perfect equilibrium. Let us now take a huge sphere of lead weighing five tons and place it two feet under one scale pan. It will exert an attractive force on the lead ball and will disturb the equilibrium of the balance. In order to restore the equilibrium of the balance an additional weight of one half of one milligram (or 1/130 grain) will have to be placed on the other pan. Thus the attraction between five tons and ten pounds at a distance of two feet is only equal to the attraction of the earth on one half milligram. This experiment enables us to determine the mass of the earth to be 6×10^{21} tons. Astronomically speaking, this mass is small. The smallest astronomical mass which has been measured is 5×10^{16} tons. This is the mass of one of Jupiter's satellites and it was only measurable on account of the presence of another satellite near it. The mass of the sun is measured by means of its attraction on the earth, and is found to be 2×10^{27} tons. This means that, if 1000 such earths as ours were to be moulded from the material in the sun only one-third of one per cent. of the sun would be required.

Computation from Double Stars

In measuring the masses of the stars themselves we are limited by the fact that we can only measure stars having other stars near them, that is, double stars. There are thousands of these double stars, and in about a hundred cases these have been observed sufficiently to work out their orbits and hence their masses.

By Kepler's third law we have

$$m_1 + m_2 = a^3/P$$

where m_1 and m_2 are the masses of the two stars, a is the distance between the two stars, and P is the period.

The period is determined fairly simply, but in the determination of the distance difficulties are met with. If the plane of the orbit were at right angles to the line of sight the distance would be readily obtained, but this ideal case is the exception, not the rule. Hence we must be able to find how much the orbit is tilted, which enables us to determine the actual distance from the apparent distance. Since the orbit is elliptical there will be a maximum and a minimum apparent separation of the two stars. The mean

of these will give the value of a. Having found our value for a we only need the scale in astronomical units to make our information complete.

If a'' be the separation in seconds of arc, and p be the parallax, we have a in astronomical units $= a''/p$.

Consequently $m_1+m_2=a''^3/P^2p^3$.

In order to evaluate m_1+m_2, then, we must obtain the orbit of the stars, which is fairly easy, and their parallax which presents greater difficulty. Since the cube of the parallax appears in the equation it is evident that a ten per cent. error in the parallax will cause a thirty per cent. error in the value for the mass.

It is generally impossible to determine the individual masses, m_1 and m_2. In cases where these masses can be determined, we must examine their movements with respect to the stars in the background. For, since each star revolves around their common centre of gravity and the centre of gravity moves on a straight line, the stars will oscillate from one side to the other of this

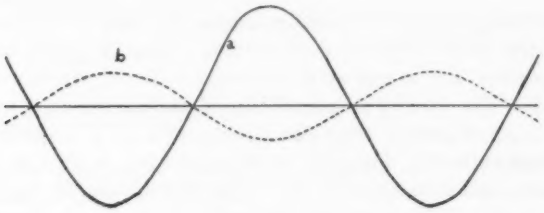


Fig. 10. Diagram illustrating the motion of the components of a double star across the straight line in which their centre of gravity moves— *a*, lighter mass; *b*, heavier mass

straight line (Fig. 10). A study of these oscillations gives the relative masses, since the products of the masses into their respective distances from the centre of gravity must be equal.

These investigations show that the brightest stars have the greatest masses, but that the change in brightness is not at all proportional to the change in mass; a thousand, or even a ten thousand-fold change in brightness being produced by a two or a three-fold change in mass. A good example of this is the case of

Sirius, in which the main component is 10,000 times brighter than its companion while its mass is only 2½ times as great.

The following table gives the masses of both components of a few double stars, the sun's mass being taken to be unity:

Star	Larger Component	Smaller Component
Sirius	2.5	1.0
Procyon	1.0	¼
α Centauri	1.0	.8
Castor	3.5	2.7
Krüger 60	.3	.16

The smallest double measured is Krüger 60, which is shown in the table, while the greatest so far measured is κ Pegasi, whose mass is 16 times the mass of the sun.

Use of Spectroscopic Binaries

Spectroscopic observations are frequently used in the determination of the orbits of these double stars. Now a spectroscope can only indicate the component of velocity in our direction. This means that the velocity measured is smaller than the actual velocity, and that consequently the value determined for a is smaller. If i is the inclination of the orbit of the star, then $a \sin i$ is what we determine, and consequently our values for the masses are $m_1 \sin^3 i$ and $m_2 \sin^3 i$. If we consider the orbits to be in all directions in space, no more in one direction than in any other, we can apply the law of probability. From this we find that the average mass determined is 60 per cent. of the actual mass. In this way we obtain values for the masses of many other stars.

A great number of spectroscopic doubles are very white and extremely hot stars, a class which is not found in telescopic doubles. The greatest mass of a double of this type is that of a sixth magnitude star in Monoceros, discovered by Dr. J. S. Plaskett, in which the masses of the components are 75 and 63 times the sun's mass. This is exceptional, however, the average mass usually not exceeding 15 or 20 times that of the sun, and sometimes being much smaller.

The following table gives the approximate maximum and minimum values of the various stellar measurements, referred to the sun as unity.

Characteristic	Maximum	Minimum
Size.....	500	1/2
Bulk.....	125,000,000	1/8
Brightness.....	10,000	1/10,000
Mass.....	100	1

Method Using a Small Part of the White

Two independent investigators, of whom Professor Russell is one, have developed simultaneously a means by which it is now possible to extend the above method to stars which have moved through a very small part of their orbits. Let us first consider the simplest case in which the plane of the orbit is perpendicular to the line of sight. If r be the radius of the circle, the distance around the orbit will be $2\pi r$. And if v be the velocity of the star then the period

$$P = 2\pi r/v.$$

Now, by Kepler's third law,

$$m_1 + m_2 = r^3/P^2.$$

Therefore, substituting the above value of P,

$$m_1 + m_2 = v^2 r/4\pi^2.$$

If p be the parallax, r'' the angular radius and v'' the true velocity in seconds of arc per year, then

$$r = r''/p,$$

and

$$v = v''/p.$$

Therefore, on substituting these values,

$$m_1 + m_2 = v''^2 r''/39\ p^3.$$

The orbits of these stars, however, are not at right angles to the line of sight but are tilted. As a result, the apparent distance measured, s, is less than r, and the apparent velocity, w, is less than v. Consequently the apparent mass, which is equal to $sw^2/39\ p^3$, is less than the actual mass. If we apply the theory of probability we are able to say that, on the average, the apparent mass is 45 per cent. of the true mass. This gives us the expression for the mass

$$m_1+m_2=sw^2/17\ p^3.$$

Naturally large errors will be introduced in individual cases, but, on the average, the error is eliminated. This method was tested by Professor Russell on 100 stars whose orbits were known, the result being within one or two per cent. of the actual values. Consequently the material on which we can work is greatly increased, since we do not have to wait thousands of years in order to determine the orbit. At present there are 1600 double stars for 300 of which we have parallaxes, so that, as soon as we obtain the parallaxes, we can determine the masses of 1600 stars.

Mass and Brightness

These investigations into the masses of the stars have shown us that stars of equal brightness have approximately the same mass, regardless of their colour, while brighter stars have greater masses than fainter ones. The following table gives a comparison between the light given off by a star and its mass.

Light.....	1000	100	2	1/200
Mass.....	10	5	2	0.6

Thus we see that the range in mass is extraordinarily small for the range in brightness.

This result is confirmed by information from other sources. This enables us to apply our formula in the opposite direction. For, since we are able to say that stars of a given brightness have the same mass, we can place the value for the mass in our formula and obtain the parallax. Of course, stars of the same brightness are not exactly alike, but the error introduced is less than that introduced by other methods. Perhaps the greatest source of error is the foreshortening due to the inclination of the orbit. The error due to this is probably about 20 per cent. of the parallax, which, as has been said, is somewhat better than usual.

Densities of the Stars

The results which we have obtained for the masses of the stars when combined with the results for their radii enable us now

to answer our question as to whether the masses of the stars are proportional to their bulk. The weight of evidence is against large stars having large masses, and causes us to believe that the giant stars have a very low density, that is, are gases at low pressure. The following table will serve to show the relation between bulk and mass.

Star	Radius	Bulk	Mass	Density
Sun.....	1	1	1	1
α Centauri...	1	1	1	1
Sirius.....	1.8	6	2.5	0.4
Krüger 60....	1/3	1/27	0.3	8
Arcturus.....	30	27,000	10.0	1/2700
Antares.....	450	100,000,000	50.0	1/2,000,000

Thus it is seen that Arcturus has a density one-third that of air, while Antares has a density 1/2000th that of air. This density is that of what is ordinarily called a vacuum, and is about the same as that of the familiar incandescent bulb.

Still another way of arriving at the density of a star is available when the double star is of the eclipsing, variable type. As has been shown, from the light curve we can determine the relation between the sizes of the two stars and the size of their orbit. Spectroscopic observations enable us to determine the actual velocity of each star in the line of sight and, from this, the relative masses of the two stars.

Let m_1, m_2 be the masses of the two stars,
r_1, r_2 be the respective radii of the two stars.
a be the radius of the orbit,
P be the period of revolution.

We have

$$r_1 = k_1 a$$

where k_1 is known from the light curve

and $$m_1 + m_2 = a^3/P^2.$$

Now, from spectroscopic observations the value of

$$\frac{m_1}{m_1+m_2} = y$$

can be determined.

Hence $m_1 = y\,a^3/P^2$.

Now the density

$$\rho_1 = \frac{m_1}{r_1^3} = \frac{ya^3}{P^2} \Big/ k_1^3\,a^3 = y/P^2k_1^3.$$

Therefore, having determined y, k, and P, we are able to evaluate the density, ρ_1, of the star under consideration.

In general, our investigations into the masses of the stars lead us to believe that the white stars have a density of about 10 times that of the sun, that yellow stars have a density comparable to that of the sun and that the red stars have densities ranging from 1/100th to 1/1000th that of the sun.

How a Gaseous Star Can Eclipse Another

The question may now arise as to how a star composed of rarefied gas could cut off all the light from one behind it so as to cause an eclipse. A consideration of the passage of light through our own atmosphere will easily answer this. Sunlight traversing 50 miles of our atmosphere is reduced to 10 per cent. of its original amount. If it travels through 100 miles only 10 per cent. of 10 per cent. is transmitted. Thus it can readily be understood that light passing through several millions of miles of gas, even if that gas is at very low pressure, will be entirely absorbed and the body of gas will be effectively opaque.

(*To be continued*)

THE RADIAL VELOCITIES OF FOURTEEN STARS

By W. H. Christie

DURING the summer months of 1923 the writer was employed as observing assistant at the Dominion Astrophysical Observatory to help with the observing during the temporary absences of the regular members of the staff. He was also engaged in bringing up to date a card catalogue of the radial velocities of the stars, and in addition he had some available time for measuring spectrograms for radial velocity.

The spectra of fourteen stars from a general programme of H. R. stars, for which a sufficient number of plates had been obtained to give a reliable velocity, were measured by the writer and the results are given in the following table of individual velocities. The spectrograms were made with the universal spectrograph, attached to the seventy-two inch reflector; and nearly all of these, with the medium focus camera and single prism which gives a dispersion of about twenty-nine Angstroms to the millimetre at $H\gamma$. A few, however, were made with the short focus camera and single prism, which gives a dispersion of about forty-nine Angstroms per millimetre. The width of the slit was .051 mm. and this gives excellent definition with the medium focus camera. The resolving power of this spectroscope is so good that once when the slit was inadvertently narrowed slightly the two close pairs of iron lines in the comparison spectrum, to the violet of 4200, were clearly resolved.

All but two of the plates in the following list were measured on the micrometer engine, and reduced by the method described in Vol. II, No. 1, *Publications* of this observatory. The other two were measured on the Hartmann spectro-comparator, using the alternate sections 7 to 23, and reduced in the manner also described in the above publication.

Star α, δ (1900)	Type Mag.	Date G.M.T.	Rad. Vel.	Lines	Remarks
H.R. 526 S	A2	1922 Sept. 23.897	−11.7	4	Binary. This star
$1^h\,43^m.3$	6.0	Oct. 19.887	−23.4	4	with the next
+47° 24′		Nov. 28.758	+2.5	6	forms the visual double Σ 162 = B.G.C. 941.
		1923 Aug. 14.884	−42.5+60	10	Red component two
		" 18.941	−1.9	6	lines only.
H.R. 526 N	A2	1922 Sept. 17.940	+1.5	9	
$1^h\,43^m.3$	6.0	Oct. 19.845	−5.3	9	
+47° 24′		Nov. 28.665	−5.0	9	
		1923 Aug. 14.958	−4.3	15	Good plate.
			−3.4±1.1		
H.R. 647	F0	1921 Aug. 25.994	−7.9	22	
$2^h\,7^m.6$	6.0	1922 Sept. 5.939	−8.1	19	
+47° 2′		" 15.973	−9.2	20	
		Nov. 21.724	−5.7	13	
			−7.7±0.5		
				13-23	Both plates
H.R. 949	G5	1922 Sept. 5.997	−32.3	8	measured on
$3^h\,5^m.5$	6.4				Hartmann com-
+47° 22′		" 17.991	−32.1	16-23	parator and
			−32.2	8	measuring engine. Mean of two measures given.
H.R. 5445	A0	1922 Apr. 23.931	−13.7	26	
$14^h\,29^m.9$	6.3	May 7.793	−6.7	13	
+32° 59′		" 19.841	−10.4	17	
			−10.3±1.4		
H.R. 5472	F5	1923 June 3.836	−18.7	7=23	Binary.
$14^h\,35^m.8$	6.2	" 18.794	−34.6	7=23	
+22° 24′		Aug. 14.686	+4.4	19	
		" 20.710	+15.2	12	
H.R. 5731	B9	1923 Feb. 28.067	−16.3	3	4481, H_γ +K
$15^h\,20^m.7$	5.8	May 23.821	−31.7	6	
+62° 23′		July 1.739	−23.5	3	4481, H_γ +K
		" 27.742	−14.5	2	4481, H_γ
			−21.5±2.6		

Star $\alpha, \delta(1900)$	Type Mag.	Date G.M.T.	Rad. Vel.	Lines	Remarks
H.R. 5752	A0	1922 Feb. 27.071	−26.6	21	Binary.
$15^h\ 25^m.6$	6.0	Mar. 24.987	−16.6	22	
+47° 35′		Apr. 18.948	−11.5	18	
		May 9.849	+ 7.6	17	
H.R. 6351	A3	1922 Apr. 18.996	−49.5	9	Binary.
		May 9.888	−14.7		
$17^h\ 0^m.3$	6.0		−10.6	6	Violet component
+34° 56′		" 28.898	+54.1	4	one line only.
			−41.3		
		1923 Aug. 6.722	+38.3	9	
			−61.7		
H.R. 6466	F8	1923 Apr. 23.992	+13.4	6	Interagreement of
$17^h\ 17^m.7$	6.3	May 7.869	+6.6	5	individual measures
+28° 51′		Aug. 14.746	−13.5	19	of lines poor.
			+2.2		
H.R. 6924	B3	1922 May 9.978	−23.4	3	Binary.
$18^h\ 22^m.7$	6.4	" 26.944	− 0.2	4	
+26° 23′		June 27.775	−15.4	7	
		July 14.858	−73.0	3	
H.R. 7267	F5	1923 July 27.819	+ 3.9	14	Binary. First plate
$19^h\ 4^m.2$	6.5	Aug. 4.747	+ 78.5		mean of two
+16° 42′			− 75.2	13	measures.
		" 8.751	+ 7.0	18	
		" 14.805	+101.8		
			− 68.3	9	
H.R. 7620	B3	1923 July 21.834	−25.7	8	
$19^h\ 53^m.1$	6.0	" 27.860	−18.5	8	Mean of two
+35° 59′		Aug. 4.781	−21.7	7	measures
		" 6.786	−26.9	8	
			−23.2±1.3		
H.R. 8528	A0	1921 July 30.921	−10.0	7	
$22^h\ 17^m.6$	6.3	1922 Sept. 5.805	−18.4	9	
+41° 36′		" 15.802	−22.3	10	
		Oct. 10.797	−22.5	5	
			−18.3		

To obtain the probable error the well-known formula $r = \pm .6745\sqrt{\Sigma v^2/n(n-1)}$ was used. The accepted velocity and its probable error are printed in heavy type below the individual measures of each star. The table itself is self-explanatory. It will be noted that six of the fourteen stars are of variable velocity.

I would like to take this opportunity of expressing my appreciation of the kindness shown me by Dr. Plaskett and his staff during my stay at the observatory. Their patience and constructive help made my stay a never-to-be-forgotten one.

Victoria,
British Columbia.

THE WORK OF THE TELESCOPE*

By J. S. Plaskett

Prevalent Misconceptions

THE general idea of an astronomer's work, as gathered from the questions and remarks of visitors, is that he sits at the eyepiece of the telescope sweeping the heavens in a search for new planets, comets or stars. The absolute futility of such a use of the telescope is evident when it is realized that the main field of the 72-inch covers only about one hundred-millionth of the sky and if only five seconds was required to examine each field it would take more than a lifetime to go over the whole sky once. A second misconception is the idea that large telescopes are used for visual observations of the planets with special reference to their habitability. No work is being attempted at this or other large observatories on planetary detail for which about an 18-inch refractor gives the best results and such a large telescope as the 72-inch is quite unsuited. All scientific observations with the 72-inch are made photographically and it is only arranged for visual use on Saturday evenings when for two hours visitors are allowed to observe the heavenly bodies. A third misconception is that the astronomer only works at night. However true this idea may have been in the days of visual observations when the measurements were made at the eyepiece, there is certainly now, when photography is so generally applied, more day than night work in astronomy. Besides the advantages of permanency, accuracy of measurement and power of recording objects beyond the range of the keenest eyesight, the photographic method has the further great advantage that an hour's exposure may give sufficient material for several days' measurement and discussion.

Spectroscopic Work

As already indicated most of the work with the 72-inch telescope is spectroscopic, but as also indicated modern spectroscopic investi-

*From a booklet describing the Dominion Astrophysical Observatory.

gations cover so wide a range of research that the actual work of the observatory is very varied. By aid of suitable spectrographs attached to a large telescope we can measure the speed of the stars towards or from us, their radial velocity as it is termed. We can discover double stars too close ever to be seen double in any telescope and we can determine the manner in which they revolve around one another and their distance apart and mass. From the spectra of the stars we can determine their absolute brightness as compared with the sun and their parallax or distance. The chemical elements present in the outer atmospheres of the stars can be determined and the pressure in these atmospheres. The measurement of temperatures and other physical conditions in the stars by means of the spectroscope is now an accomplished fact and one of the most recent developments of the spectroscopic work here has been to provide evidence of the truth of a theory of atomic structure and to show that the atomic constants in the enormous furnaces of the stars are the same as on the earth. Such a catalogue of information, obtained from an investigation of the mere quality of the light from stars so faint as to be quite invisible to the unaided eye and so distant that it may take thousands of years to travel to us, is sufficiently comprehensive to be treated in more detail.

Radial Velocities

When the 72-inch telescope was in course of design and construction, one of the greatest needs in astronomical work was increased data in regard to the radial velocities of the stars. Although the telescope was so designed as to be suitable for all kinds of observational work, special attention was devoted to the spectroscopic end. After consultation with the most prominent astronomers an observing programme of about 8000 stars whose "proper" or cross motions across the sky were accurately known but whose radial velocities had not been determined, was prepared and spectroscopic observations of the stars on this programme were commenced as soon as the telescope was completed in May, 1918. After slightly over three years' work, observation and measurement were completed and Vol. II, No. 1, of the observatory publications, "The

Radial Velocities of 594 Stars," was published early in 1922. As hitherto the radial velocities of only about 2,000 stars had been obtained, this work was a considerable addition to existing data about the motions of the stars and will be of great use in extending our knowledge of the structure and motions of the universe. A second programme of 1,500 stars has been prepared but owing to other intervening observational work, not much has yet been done on this new programme.

One of the auxiliary programmes undertaken and nearly completed since the first programme is the determination of the radial velocities of a very interesting but limited class of stars, the highest temperature stars known, the O-type stars. The radial velocities and other interesting data of about 50 of these stars have been completed.

Spectroscopic Double Stars

In the measurement of the radial velocity of the 800 stars on the first programme it was found that in about 180 stars successive plates did not give constant velocities, the stars at one time approaching at another receding from us. This phenomenon is practically certain proof that we are measuring the velocity of a star revolving around an invisible companion and such stars are generally called spectroscopic binaries to distinguish them from visual binaries which can be seen double in the telescope. Over 200 spectroscopic binaries have been discovered at this observatory as compared with about 700 discovered elsewhere, again a considerable addition. In about 20 of these binaries, observations were continued until the period of revolution, the form of the orbit, the separation of the two stars and in some cases, their masses were determined. In a particular class of spectroscopic binaries, the eclipsing variables, which allow from the combination of spectroscopic and photometric measurements the absolute dimensions to be obtained, we were able to determine the separation of the two stars, their diameters, densities, masses and brightness and the probable distances. Such complete information has been obtained here about seven systems, while only seven other systems have been determined elsewhere.

Absolute Magnitude and Distance

A new application of spectroscopic methods is to the determination of the total brightness of the stars as compared with the sun and their distance or "spectroscopic parallax" as it is called. This depends not on the positions but on the relative intensity or strength of the lines in the spectra of the stars and has only been developed in the last three or four years. The absolute magnitude and spectroscopic parallax of about 800 stars is now nearly completed and will soon be published while as a side line the radial velocities of 125 more stars have been determined.

Physical Conditions in the Stars

The spectrographs have also been used by one member of the staff in the determination of the physical and chemical conditions in stellar atmospheres, a new and difficult problem but one which promises not only very valuable additions to our knowledge of the constitution of the stars but may also lead to economic applications of the greatest importance. A new method depending upon the use of a wedge of dark glass has been applied to determining the distribution of energy in the different parts of the spectrum of the stars and to measuring their temperatures, while an application of the same methods to individual lines may lead to a great increase in our knowledge of conditions in the stars. A special investigation of three of the high temperature O-type stars referred to above has proved the existence in the spectra of these stars of lines predicted as present from purely theoretical conditions but never previously identified and has thus remarkably verified a theory of the structure of the atom. The measurement of the wave lengths of these hitherto unknown lines has led to an important independent determination of the fundamental constants of atomic structure and the dimensions of the atom and has shown that these constants and dimensions are the same in the tremendous furnaces of the stars as in our terrestrial laboratories, a verification of the homogeneity of matter and the uniformity of physical laws throughout the universe. Further interesting results from this investigation are the application of a new

theory of ionization with the probable relative abundance of the elements to an independent determination of the temperature of these stars.

Other Investigations

Direct photographs have been made of some nebulae and clusters but this work is not being definitely followed at present. Investigations into the phenomena accompanying some short-period binaries have been made and into the behaviour of the two strong calcium lines H and K in the spectra of the high temperature stars from which interesting and valuable results are expected. Since the observatory commenced work two bright novae or new stars have appeared, which have been fully observed spectroscopically here and the results discussed. The plates of the nova in Aquila have been loaned to the observatory at the University of Cambridge, England, for fuller discussion and analysis.

Value of Astronomical Work

This brief sketch of the work of the observatory naturally leads to the question frequently asked of astronomers:—What use is the work done at observatories and what practical value can a knowledge of the stars have in everyday life? While astronomy has obvious practical applications to navigation and surveying yet nine-tenths of modern astronomical research is devoted to the more or less abstract question of the constitution and motion of the stars and the structure of the universe. Indeed most physical and chemical as well as astronomical research is undertaken for the purpose of increasing our knowledge and of investigating the secrets and laws of nature and has generally no direct practical economic application. But it is now generally recognized by the layman as well as the scientist that without abstract there can be no applied science and that all the great economic and industrial applications of science have had to be preceded by the abstract and apparently non-practical investigations of pure science. The Great War perhaps made more evident than ever before the absolute dependence of applied science upon the unselfish and abstract work of pure science.

Economic Value

In view of past experience in science it would hence be a rash prediction to assert that the investigation of the conditions in distant stars can have no practical application upon earth. It may be of interest to point out one possible application of astrophysical research.

It is generally agreed that one of the most important economic problems of the not far distant future will be the provision of sources of energy to replace our rapidly depleting supplies of coal and oil. It appears now that the most probable solution of this problem will consist in the development of some method for utilizing the inexhaustible stores of energy contained in the atoms of matter. Modern research on conditions in the stars has made it practically certain that the enormous supply of energy, which has been radiated into space for aeons of time from these bodies, can only be maintained undiminished by the energy released by the transformation of atoms in the interior of the stars, where conditions of temperature and pressure prevail at present unattainable in terrestrial laboratories. The most hopeful line of attack upon this tremendously important economic problem hence seems to lie in the systematic astrophysical investigation of conditions in the stars supplemented by physical and chemical researches on the structure of the atom.

Ethical Value

While astronomers and scientific men generally fully realize the value of the practical applications of science, their main purpose is the search for truth and the extension of our knowledge of nature. While it is possible that investigation of the stars may have immense economic value, it is certain that it has tremendous ethical value, giving us a clearer knowledge of the laws of nature and of our relations to the wonders of creation. Astronomy is the oldest and in many respects the most important of the sciences, and its study through the ages has been one of the most elevating influences on human character. Poincaré has well said that if the earth had been so continuously covered with clouds that the heavenly bodies could not be seen, mankind would still be in a primitive state and under

the domain of superstition. The main superiority of modern over ancient civilization does not consist in the greater abundance of the necessities and luxuries of life, although this is undoubtedly due primarily to scientific research, but to the elevating influences of the truer conceptions of nature made possible by the abstract study of astronomy and other sciences.

It has been truly said that the degree of civilization of a country may be judged by the support it gives to the study of astronomy. By the establishment and maintenance of the Dominion Observatory at Ottawa and of the Dominion Astrophysical Observatory at Victoria with the second largest telescope in the world, Canada has a just claim on this criterion to the favourable estimation of the scientific world.

Victoria, B.C., May, 1923.

REVIEW OF PUBLICATIONS

Littrow's Atlas des gestirnten Himmels für Freunde der Astronomie, mit einer Einleitung von Professor J. Plassman, 3 Auflage, $4\frac{1}{4} \times 6\frac{1}{2}$, Berlin, Ferd Dümmlers Verlagsbuchhandlung, 1924. Price, 3.15 Swiss francs.

This is a very convenient pocket edition of Littrow's Atlas designed especially for amateurs. There are 48 pages of text, 14 maps of the constellations (covering the entire celestial sphere), 3 maps of clusters, and one of the moon. In the introduction there is an explanation of the various terms used in fixing the position of a body, such as meridian plane, right ascension, etc., and following that is a brief description of the constellations with instructions for locating them. On four pages are given the positions (right ascension and declination) of the planets for every five days of 1924 and 1925. The little book is bound in boards.

The Poetical Works of Albert Durrant Watson, 342 pages, $5\frac{1}{2} \times 8\frac{1}{2}$ inches. Toronto: The Ryerson Press, 1924. Price $3.

Dr. Watson is a physician in a "down-town" district of Toronto. When he went to live there it was occupied by good residences, but the encroachment of business and the influx of foreigners has altered its complexion somewhat. Though he has been urged to move away, he still remains there, and as a consequence he is known throughout the neighbourhood, not only as an aid in time of illness but also as an adviser and friend when religious, social or economic trials arise.

For twenty years Dr. Watson has been cultivating the field of letters. His first books were in prose, but since 1908 he has published five volumes of verse. The present one contains all his poetical work which he cares to have perpetuated, and in it is a considerable number of pieces which are now first printed.

In addition, Dr. Watson is a capable amateur astronomer and has been connected with the R.A.S.C. for many years, being its president in 1916 and 1917. As one might expect, he is a lover of

nature in all its manifestations, and we continually see references in his verses to the sky, the wind, the tides, the silver moon, the stars. In his later poems there is somewhat of the mystical element. A distinguishing feature, however, is that in everything he writes he ever keeps before him the beautiful and the good—peace, love, harmony, the higher life.

Some of the poems extend to several hundred lines and the themes are always treated in a lofty and dignified way, but to the present writer some of the shorter ones make a stronger appeal.

The last portion, comprising seventy pages, is entitled "The Immortals." It contains monologues supposed to be uttered by various great historical personages, such as Abraham, Caesar, Cromwell. They are in modern blank verse and retain the elevated tone and flowing phrase of true poetry, but not in the language or manner of the original speaker. Two of them, namely, Copernicus and Galileo, have already been printed in the JOURNAL, as indeed have several other poems in the book, one of the finest being the sonnet "Northern Lights" (page 9).

Some samples may be of interest to our readers. First, let us take:

THE WONDER-STAR

Now brightly in the soft-eyed southern skies,
  Between Aquarius and the Hunter's feet,
  Above where earth and heaven in shadow meet,
Mira, the star of ancient mystery, lies.
But while we gaze in eloquent surprise,
  Her blaze of transient splendour all too fleet
  Fades from our vision and no more we greet
The image of an ever vast surmise.

O Star of Wonder! thine elusive light,
  A fitting emblem of all human fame,
Burns with meridian beauty in our sight,
  Then fades to dreams of splendour and—a name.
    Thus for a day man's glory gleams afar,
    Then dims to darkness like the wonder-star.

Some of the lyrics are very beautiful, such as one within the longer poem, "To Worlds More Wide."

In the stars that gem the blue
  Of the night,
In the storm and in the dew,
  There is light;
In the clouds that split with thunder,
In the soul athrill with wonder,
Over all and through and under,
  There is Love and Light.

In the moon-gleam on the sea
  There is power,
In the suns and nebulae,
  In the flower;
In the soul of pure desire
Present always to inspire
Like a throne of pillared fire,
  There is Love and Power.

A later poem dated 1922 is entitled:

STAR-MELODIES

Through all the dissonance that mars
  The harmony of time,
I hear the pibroch of the stars
  Burst forth in tones sublime:
It is the music of that lyre
  That out of chaos flung
Its wail of melody and fire
  While yet the world was young.
And whensoe'er earth's shadow bars
  The highway of the light,
The cadence of the silver stars
  Comes throbbing down the night.

In "Love and the Universe" is the following verse:

Where Neptune's breath the salty spray is sweeping
  Along the silent seas,
There dwells the God of gods whose will unsleeping
  Moves the eternities.

I peer into the blue serene above me,
  Where constellations roll,
And find a Power that cares for me and loves me,
  The Keeper of my soul.

I shall close with the following:

THE SINGING SKIES

The stars are waiting until our hearts are wise;
  They glow and throb, all vibrant with the thought
That some day we, beholding with clear eyes
The deep celestial splendour of the skies,
  Shall know all beauty out of love was wrought.

NIGHT

Come, gentle Sister of the starry skies,
  With sable fingers open to our sight
Those fields of unimaginable skies—
  Your vast demesne—Come, gentle Sister, Night.

Come in the silence. Let us hear afar
  The tramp of Time's retreat, diminished long,
Till night and quiet light and music are,
  And in our souls is everlasting song.

C. A. C.

NOTES AND QUERIES

Communications are Invited, Especially from Amateurs. The Editor will try to Secure Answers to Queries

Reform of the Calendar

The following information regarding the progress made in the recent proposals to reform our present calendar is taken from an article in *Popular Astronomy* for March by Father W. F. Rigge, who based it upon papers by Father J. G. Hagen, Director of the Vatican Observatory.

The much discussed question of the reform of the calendar has gained fresh prominence from recent developments. In July, 1923, the League of Nations invited the Holy See to send a representative to a conference at Geneva to discuss the subject. The fact that the invitation was accepted was an indication of the attitude of the Roman Church. The Greek Church and the Anglican Church also sent a representative by request, but no other religious denominations were invited. These representatives held the view that there should be no dogmatic difficulty in shifting the ecclesiastical feasts but that the consent of all bodies affected must first be obtained. In pursuance of this, the resolution of the conference was sent to the heads of all governments and religious denominations, with the request that an answer be returned before March 1st, 1924. A standing committee, including the three representatives, was then appointed.

The extent of the problem will depend on whether there will be merely a revision of the ecclesiastical feasts, or with it, also a change in the calendar. For instance, Easter now shifts over a range of five weeks and causes great inconvenience in certain walks of life. It would be much simpler to have Easter on a definite date.

Numberless schemes have been advanced to create a greater uniformity in the calendar. Practically all of them agree on one point, namely, the adoption of blank days. A year would contain 52 weeks and one blank day, not assigned to any week; a leap year would contain two blank days. An advantage of this

system lies in the fact that it would be possible to have thirteen months of exactly four weeks each, the same date of each month always falling on the same day of the week. This simplification would be a great convenience to the business world. The disadvantage lies in the fact that every year there would be one interval of eight days between Sundays, and every leap year there would be one of nine days. It is most probable that Christian and Jew alike would object to this departure from religious custom, unless the difficulty could be avoided by making the extra day Christmas day, or some similar idea.

All successful calendars have been based on some cycle. An ingenious system has been suggested by G. M. Searle, basing the calendar on the Gregorian cycle of 400 years. In each year there is one day left over, or a total of 400 days in the cycle. In each leap year there is one extra day or $400/4-3=97$ days. These 497 days make 71 weeks, so that there is an integral number of weeks in a Gregorian cycle. It is suggested that these extra weeks be tacked on to certain years in the same way as the extra days are at present. This could be accomplished by the following rule:

"Every year whose number ends in a '5' or a '0' would be a leap year, except those which end in a '50' or a '00' and when it begins a new cycle." This rule is much simpler than the present one, which uses multiples of 4 instead of multiples of 5. It would then be possible to have the thirteen months with a blank week, unattached to any month, every leap year. This would avoid disturbing the time-honoured seven-day week and would call forth less objection from ecclesiastical bodies, and at the same time facilitate matters for the commercial world.

At the coming conference there are two main questions to settle:

(1) Shall the date of Easter be fixed without changing the calendar?

(2) Shall the calendar be revised according to one of the above plans?

Also two accessory questions:

(1) Shall the length of the months be changed, and how?

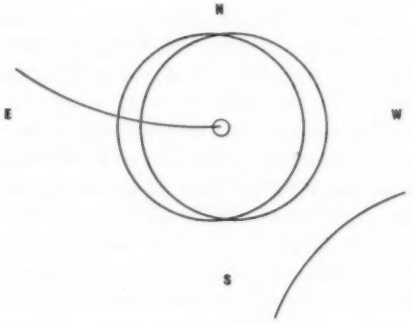
(2) How are the ecclesiastical feasts to be arranged in the new calendar?

A. W. E.

SOLAR HALO SEEN AT TIVERTON, ONT.

Rev. N. R. D. Sinclair of Tiverton, Bruce County, Ont., in a note to Mr. A. F. Hunter, describes a solar halo which he saw on March 20, as follows:—

"To-day at noon and for some time after it we had the pleasure of seeing one of those beautiful displays connected with the sun. I am enclosing a rough sketch herewith. There were two halos around the sun but they were not concentric. Rather the sun seemed to be in the centre of the two of them, so to speak, and where they crossed each other above and below the sun they were exceptionally brilliant. Then there was an arc of a large circle ex-



tending out toward the east from the sun. This was not so highly coloured. And below and to the west there was another arc of the colour of a rainbow bending away from the sun.

I am sending this merely as an account of an interesting meteorological phenomenon. My drawing will not be accurate as to scale, but it will give some idea as to how it appeared to me."

Mr. Hunter states that this halo resembles one which he himself observed on May 31, 1904, and which is referred to in this JOURNAL on page 4 of Volume 12, 1918. To him it appeared as an elliptical halo with a circular one within it and touching it at two points.

C.A.C.

MEETINGS OF THE SOCIETY

At Toronto

March 11.—The regular meeting of the Society was held in the Physics Building of the University at 8 p.m., the 2nd Vice-President, Mr. A. F. Hunter, in the chair.

The following were elected Members of the Society:

Mr. Edward Scott, 316 Dupont St., Toronto.

Mr. S. Humphrey, M.A., Unity, Saskatchewan.

Mr. E. G. Hartshorn, 1533 16th Avenue W., Calgary, Alta.

Dr. Alvin Martin, 991 Woodbine Ave., Toronto.

Mr. A. F. Hunter gave the predictions of phenomena. He pointed out that both Venus and Saturn were now favourably situated for observation and spoke of the coming opposition of Eros.

Mr. A. F. Miller and Mr. A. F. Hunter both reported observations of Betelgeux, their conclusion being that it is now inferior to Rigel in brightness and that it had been brighter last September.

Mr. Collins gave a short talk on Ursa Major, explaining how to find it, and showing its relation to the hour circles.

Mr. A. F. Hunter spoke of the dark nebulae described by Prof. Russell in his series of lectures. In order to illustrate his ideas of the gaseous origin of the nebulae several slides were shown, in which the dark patches appeared bright, and the bright patches dark.

Dr. Chant referred to evidence which shows the dark nebulae to be real substances, opaque to light. Since, according to Campbell, the stars are moving with an average velocity of 20 km. per second, it is impossible to account for the dark spaces except by the presence of an opaque body. He also pointed out how the problem of the measurement of the size of the universe was very clearly treated and how the stellar and solar phenomena were reconciled with the theory of the atom and ionization.

Mr. A. F. Miller spoke of the great benefit received by those privileged to attend the lectures. He spoke of the Michelson interference method of measuring stellar diameters and concluded that the reason that a large telescope was used in place of a small one was not the size of the mirror but the fact that the larger the telescope the more massive it is and consequently the apparatus can be more easily carried.

He also spoke of Hubble's theory that the nebulae are luminous by the action of a star, and pointed out that there must be exceptions to this theory. Such exceptions were exemplified by the filamentous nebulae in Cygnus, which are

very large and seem evenly illuminated, a thing impossible with one star as the source. The great Andromeda nebula is another apparent exception.

Mr. Miller also spoke of the Novae, describing the spectrum of Nova Perseion at various times in its development. He suggested that the "Unknown source" referred to by Prof. Russell might be in the electrons rather than the protons, and also raised the question as to whether our sun might not at some time have been a Nova.

Dr. Chant took as his subject, "Incidents in the life of Sir Wm. Herschel." After explaining the important incidents in the life of Herschel he then read the poem, "Sir Wm. Herschel Conducts" from "The Torch-bearers" by Alfred Noyes. This poem is a monologue by Herschel just before he conducts his orchestra and choir for the last time in Handel's "Messiah" before changing from the profession of music to that of astronomy.

H. F. BALMER, *Recorder.*

At London

January 11, 1924.—The regular monthly meeting of the London Centre was held in Room 4, University of Western Ontario, Dr. H. R. Kingston, the President, in the chair.

Dr. Kingston gave an address on "The Recent Eclipse of the Sun," illustrated with moving pictures, taken on the island of Catalina and in Mexico. As an introduction to the pictures an explanation was given of the way in which eclipses of the sun are brought about, the frequency with which they occur and certain phenomena connected with them. Slides were used to show (1) the occultation of Venus by the moon, (2) the paths taken by eclipses of the sun for the period of years from 1873 to 1894, (3) the path of the shadow of the 1918 eclipse, (4) the path of the shadow for the 1922 eclipse, and (5) the relative position of sun, moon and earth on Sept. 10, 1923.

The first moving picture film was taken on the island of Catalina and showed the location of the camps, the instruments, the preparations for the eclipse, with a rehearsal which showed how the work was distributed among the different members of the party. Dr. and Mrs. Kingston were members of this party. Owing to bad weather conditions on the day and hour of the eclipse no pictures of the eclipse were taken.

The second film was made from pictures taken in Mexico. This film showed very clearly the progress of the eclipse. The corona appeared directly the sun was obscured and disappeared immediately the dark moon began to leave the face of the sun.

E. T. WHITE, *Secretary-Treasurer.*

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